



D E S C R I P T I O N

SEMICONDUCTOR DEVICE AND METHOD
OF MANUFACTURING THE SAME

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Technical Field

The present invention relates to a semiconductor device and a method of manufacturing the semiconductor device, and more specifically, to an improvement of a semiconductor device comprising a power MOSFET and a method of manufacturing such a device.

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Background Art

FIG. 21 is a diagram showing a cross section of a typical conventional power MOSFET. In this figure, reference numeral 81 denotes an n⁺-type Si substrate having a high impurity concentration, which serves as an n⁺-type drain layer. An n⁻-type epitaxial Si layer 82 having a low impurity concentration is formed on the n⁺-type Si substrate 81.

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A p-type base layer 83 is formed selectively on a surface of the n⁻-type epitaxial Si layer 82, and further an n⁺-type source diffusion layer 84 having a high impurity concentration is formed selectively on a surface of the p-type base layer 83.

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A gate electrode 86 is provided via a gate insulating film 85 on the p-type base layer 83 interposed between the n⁺-type source diffusion layer 84 and the n⁺-type epitaxial Si layer 82.

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In a power MOSFET of the above-described type, that is, a planar type power MOSFET, a current path to the MOS device is taken from a rear surface of the n⁺-type Si layer 81 via the n⁻-type epitaxial Si layer 82. With this structure, the resistance during the device is on (ON resistance) depends on the thickness of the n⁻-type epitaxial Si layer 82.

Meanwhile, a depletion layer extends within the n⁻-type epitaxial Si layer 82, and therefore the maintenance of the withstand voltage is determined by the thickness of the epitaxial layer. Typical values of the ON resistance and withstand voltage are 1.52 (Ω) and 746 (V), respectively.

As described above, in the conventional power MOSFET shown in FIG. 21, the current path and the region where the withstand voltage is maintained are located at the same place. With this structure, if the thickness of the epitaxial layer is increased to raise the withstand voltage, the ON resistance is increased as well. On the other hand, if the thickness of the epitaxial layer is decreased to lower the ON resistance, the withstand voltage is decreased as well. Thus, there is a conflicting relationship between these points, and it had been difficult to satisfy these points at the same time.

Especially, in the case where a drain-source reverse directional withstand voltage should be

maintained at 200V or higher, the resistance of the n⁻-type epitaxial Si layer 82 needs to be increased. However, if the resistance R_{Epi} of the n⁻-type epitaxial Si layer 82 is increased, the lowering of the ON resistance is inevitably limited with the conventional structure. Note that the terms, resistance R_{Ch} and resistance R_{JFET} indicate the channel resistance and junction FET resistance, respectively.

However, recently, a power MOSFET with a new structure called super junction structure, which can satisfy the above-described points at the same, has been proposed. FIG. 22 shows a cross section of a power MOSFET with the new structure. Note that the sections of this figure that correspond to those shown in FIG. 21 are designated by the same reference numerals and the detailed descriptions therefor will be omitted.

This power MOSFET is of a planar type; however, it has the following structure. That is, n-type epitaxial Si layers 87 (87_1 to 87_6) that have an impurity concentration higher than that of the n⁻-type epitaxial Si layer 82 are located at the center of the MOS, and p-type pillar layers 88 are located on both sides thereof. The p-type pillar layers 88 are formed to communicate to the p-type base layers 83, respectively. According to this structure, the current path and

the region where the withstand voltage is maintained are separated from each other.

With this structure, the main current flows through the n-type epitaxial Si layer 87, and therefore the ON resistance depends on the impurity concentration of the n-type epitaxial Si layer 87. On the other hand, the maintenance of the withstand voltage, since the depletion layer is extended in a lateral direction, is determined by the impurity concentration and width of each of the n-type epitaxial Si layer 87 and the p-type pillar layers 88. Thus, it is possible to satisfy both of the decrease in the ON resistance and the increase in the withstand voltage. Note that in the case of, for example, the 600V class, the ON resistance can be decreased to 1/3 or less of that of the planar type element shown in FIG. 21.

However, the power MOSFET with the conventional super junction structure entails the following drawbacks.

That is, in order to form the new structure shown in FIG. 22, a series of steps that include growing a thin n-type epitaxial Si layer 82, ion implantation of arsenic (As) as an n-type impurity, forming of a mask 90 for implantation of a p-type impurity, and ion implantation of boron (B) as a p-type impurity, must be repeated.

Specifically, in the case of a 600V-class element,

the thickness of the n-type epitaxial Si layer 87 is about 50 μm whereas the thickness of the n-type epitaxial Si layer 82 is about 8.3 μm . Therefore, the above-described series of steps must be repeated 5 or 6 times.

In this case, 5 or 6 times of the epitaxial growth step, 10 or 12 times of the mask formation step, and 10 or 12 times of the ion implantation step are required. After that, annealing is carried out to activate the n-type and p-type impurities that have been ion-implanted, and thus the n-type epitaxial Si layer 87 and the p-type pillar layers 88 are completed.

As described above, the manufacture of the power MOSFET having the conventional super junction structure requires a significantly greater number of processing steps as compared to the case of the planar type power MOSFET. Thus, the production cost is increased. More specifically, the production cost for the chip of the conventional power MOSFET would be almost the same as that of the planar-type large-area chip (of a low ON resistance type).

Further, in order to form a p-type pillar layer 88 such as to connect the p-type layers located above and below (, which are layers formed by ion implantation of B shown in FIG. 23D), it is necessary that B ions that are implanted should be diffused in a vertical direction (thickness direction) by at least the

thickness of the n⁻-type epitaxial Si layer 82.

During this process, B ions diffuse in a lateral direction. Therefore, there is a drawback in which the reduction in measurement of the element in the lateral direction of the unit cell (measurement in its channel length direction) is hindered by the diffusion of B in the lateral direction.

Specifically, in the case of an element of the 600V class, the thickness of the n-type epitaxial Si layer 87 is about 5 to 8 μm . Therefore, taking the diffusion in the lateral direction into consideration, the width of the unit cell of the element would be about 30 μm .

FIG. 24 shows a termination structure used in the power MOSFET having the conventional super junction structure. In this figure, reference numeral 91 denotes the source electrode and numeral 92 denotes an insulating film.

The termination structure is formed of repetitions of the n-type epitaxial Si layer 87 and the p-type pillar layers 88. In order to relax the electrical field within the n⁻-type epitaxial Si layer 82, it is necessary to increase the potential gradually from the source to drain.

Specifically, in the case of an element of the 600V class and the width of a unit cell is about 30 μm , 10 to 20 unit cells are required in terms of

the unit number. Therefore, a termination structure having a length of 300 μm to 600 μm is required. Such a long termination structure hinders the reduction in measurements of the entire device.

5 As described above, the power MOSFET with the conventional super junction structure is different from the planar type power MOSFET in that the lowering of the ON resistance and the increase in the withstand voltage can be achieved at the same time. However, the power MOSFET with the conventional super junction
10 structure entails the problem of involving a far greater number of processing steps in the manufacture thereof as compared to that of the planar type power MOSFET.

15 The present invention has been achieved in consideration of the above-described circumstances, and the object thereof is to provide a semiconductor device including a power MOSFET that can achieve the lowering of the ON resistance and the increase in the withstand
20 voltage at the same time, and also that can be manufactured without increasing a great number of processing steps in the manufacture thereof, and a method of manufacturing such a device.

Disclosure of Invention

25 Of the inventions disclosed in the present application, typical ones will now be briefly described.

That is, in order to achieve the above-described object, according to an aspect of the invention, there is provided a semiconductor device characterized by comprising: a first conductivity type semiconductor substrate; a vertical power MOSFET that employs the first conductivity type semiconductor substrate as a first conductivity type drain layer; and a separating member formed on the first conductivity type semiconductor substrate, separating the power MOSFET from other element, the power MOSFET characterized by comprising: a semiconductor structure comprising three semiconductor layers selectively formed on a main surface of the first conductivity type semiconductor substrate, the three semiconductor layers including a second conductivity type semiconductor layer and two first conductivity type semiconductor layers formed to interpose the second conductivity type semiconductor layer from both side surfaces, a pn junction boundary between the second conductivity type semiconductor layer and the first conductivity type semiconductor layer being substantially vertical to the main surface of the first conductivity type semiconductor substrate, a second conductivity type base layer formed on an upper surface of the second conductivity type semiconductor layer and having an impurity concentration higher than the second conductivity type semiconductor layer; a first conductivity type source

diffusion layer selectively formed on a surface of the second conductivity type base layer; a gate insulating film formed on the second conductivity type base layer interposed between the first conductivity type source diffusion layer and the first conductivity type semiconductor layer, and a gate electrode formed on the gate insulating film. The said other element includes the same power MOSFET as the one described above, different from the one described above, or both of them.

According to the structure described above, the semiconductor structure comprising three semiconductor layers serves substantially the same as that of the super junction structure, therefore the reduction of the ON resistance and the increase in the withstand voltage can be achieved at the same time.

Further, according to the above-described structure, the following manufacturing method of a semiconductor device allows to manufacture the device without significant increase in the number of processing steps.

According to an aspect of the invention, there is provided a method of manufacturing a semiconductor device, characterized by comprising: growing a first conductivity type epitaxial semiconductor layer having a low impurity concentration on a first conductivity type semiconductor substrate having a high impurity

concentration; making a plurality of trenches in the first conductivity type epitaxial semiconductor layer so as to reach the first conductivity type semiconductor substrate; implanting a first conductivity type impurity and a second conductivity impurity having a diffusion coefficient smaller than the first conductivity type impurity to side surfaces of the trenches by an ion implantation method, thereby converting the first conductivity type epitaxial layer in a region interposed between the trenches into a semiconductor structure comprising a second conductivity type semiconductor layer and two first conductivity type semiconductor layers formed to sandwich the second conductivity type semiconductor layer from both side surfaces by using a difference between the impurities in diffusion coefficient, a pn junction boundary between the second conductivity type semiconductor layer and the first conductivity type semiconductor layer being substantially vertical to the main surface of the first conductivity type semiconductor substrate; forming a first insulating film on at least a bottom surface and side surfaces of the trenches; forming a second conductivity type base layer having an impurity concentration higher than the second conductivity type semiconductor layer on an upper surface of the second conductivity type semiconductor layer; selectively forming a first

conductivity type source layer on a surface of the second conductivity type base layer; and forming a gate insulating film and a gate electrode on the second conductivity type base layer interposed between the first conductivity type source diffusion layer and the first conductivity type semiconductor layer.

According to the method described above, each one step of implantation of a first conductive type and second conductive type impurities into a first conductive type epitaxial layer can convert a distribution of the conductive type of the first conductive type epitaxial layer into the one required to form a semiconductor structure that serves substantially the same as that of the super junction structure.

As a result of the method, it is possible to obtain a power MOSFET having a semiconductor structure that serves the same as that of the super junction structure without significant increase in the number of processing steps

The above-described object and the other object and novel features of the present invention will be clearly described in the descriptions of this specification and the drawings attached hereto.

Brief Description of Drawings

FIG. 1 is a cross sectional view illustrating a step in a method of manufacturing a power MOSFET

(DTMOS) according to the first embodiment of the present invention;

FIGS. 2A and 2B each are a cross sectional view illustrating a step in the manufacturing method, that follows the one shown in FIG. 1;

FIG. 3 is a cross sectional view illustrating a step in the manufacturing method, that follows the one shown in FIG. 2B;

FIG. 4 is a cross sectional view illustrating a step in the manufacturing method, that follows the one shown in FIG. 3;

FIG. 5 is a cross sectional view illustrating a step in the manufacturing method, that follows the one shown in FIG. 4;

FIG. 6 is a cross sectional view illustrating a step in the manufacturing method, that follows the one shown in FIG. 5;

FIG. 7 is a cross sectional view illustrating a step in the manufacturing method, that follows the one shown in FIG. 6;

FIG. 8 is a perspective and cross sectional view illustrating a stage where the process has reached up to the formation of the n^+ -type source diffusion layer;

FIGS. 9A to 9C each are a diagram illustrating the problem that occurs when the planar pattern of the npn pillar structure of the DTMOS of the present invention is in stripes;

FIGS. 10A to 10C each are a diagram illustrating a solution to the problem of the DT MOS shown in FIGS. 9A to 9C;

5 FIG. 11 is a plan view showing a typical example of the gate wiring structure of the DT MOS of the present invention;

FIG. 12 is a plan view illustrating a solution to the problem that occurs when the gate wiring structure shown in FIG. 11 is employed;

10 FIG. 13 is a plan view illustrating an underlying structure of the gate wiring structure of the DT MOS shown in FIG. 12;

FIG. 14 is a cross sectional view taken along arrows A-A' in FIG. 13;

15 FIG. 15 is a cross sectional view taken along arrows B-B' in FIG. 13;

FIG. 16 is a diagram showing the termination structure of the DT MOS of the present invention;

20 FIG. 17 is a perspective and cross sectional view illustrating a power MOSFET according to the second embodiment of the present invention;

FIG. 18 is a cross sectional view illustrating a power MOSFET according to the third embodiment of the present invention;

25 FIG. 19 is a cross sectional view illustrating a power MOSFET according to the fourth embodiment of the present invention;

FIG. 20 is a cross sectional view illustrating a modified version of the fourth embodiment of the present invention;

FIG. 21 is a cross sectional view illustrating a conventional power MOSFET;

FIG. 22 is a cross sectional view illustrating another power MOSFET;

FIGS. 23A to 23D each are a cross sectional view illustrating a step in the method of manufacturing the power MOSFET shown in FIG. 22;

FIG. 24 is a diagram showing a conventional termination structure;

FIG. 25 is a diagram showing a termination structure of another version of the DT MOS of the present invention; and

FIG. 26 is a diagram illustrating the relationship between the distance D1 (source electrode projecting amount) and the withstand voltage.

Best Mode for Carrying Out the Invention

Embodiments of the present invention will now be described in detail with reference to accompanying drawings.

(First embodiment)

FIGS. 1 to 7 are cross sectional views illustrating steps in the method of manufacturing a power MOSFET according to the first embodiment of the present invention. This embodiment will be described

in connection with a vertical power MOSFET (DTMOS: Deep Trench MOSFET) having a novel withstand voltage structure that can assure a medium high withstand voltage of 200V or higher.

5 First, as shown in FIG. 1, an n⁻-type epitaxial Si layer 2 having a low impurity concentration (high resistance) is formed on an n⁺-type Si substrate 1 having a high impurity concentration, which serves as an n⁺-type drain layer.

10 The impurity concentration of the n⁺-type Si substrate 1 is, for example, 1×10^{19} (atoms/cm³) or higher, and the resistivity thereof is, for example, 0.006 ($\Omega \cdot \text{cm}$) or lower. The thickness of the n⁻-type epitaxial Si layer 2 is, for example, 50 μm .

15 Next, as shown in FIG. 2A, deep trenches 3 are made in the n⁻-type epitaxial Si layer 2 by means of photolithography and RIE (Reactive Ion Etching), such as to have a depth that each trench reaches the n⁺-type Si substrate 1.

20 The depth of the trench 3 is, for example, about 51 to 55 μm , the width W of the trenches 3 is, for example, about 8 μm , and the interval L between trenches 3 is, for example, about 15 μm . In order to obtain a withstand voltage of a 600V class, the depth
25 of each trench 3 should be, for example, about 50 μm or more. It should be noted here that the trenches 3 each have a shape with a uniform width in the figure;

however when the RIE is employed, an actually formed trench would have a tapered shape. That is, it would be such a shape that it is approximately vertical to the surface of the substrate.

5 Further, in practice, each trench 3 is formed by over-etching so that it surely reaches n⁺-type Si substrate 1. As a result, the level of the bottom of each trench 3 is lower than the level of the surface of the n⁺-type Si substrate 1 which is underneath
10 the n⁻-type epitaxial Si layer 2, as shown in FIG. 2B.

Next, as shown in FIG. 3, As and B are implanted into side walls of each trench 3 at an implantation angle of 5° to 7° by a rotation ion implantation method.

15 After that, annealing is carried out at 1150°C for 24 hours, and thus As and B are diffused out at the same time from both side of the n⁻-type epitaxial Si layer 2 having a mesa structure, which is interposed between trenches 3.

20 Here, the diffusion coefficient of As at 1150°C is $9 \times 10^{-3} \mu\text{m}^2/\text{h}$, whereas the diffusion coefficient of B is about $5.5 \times 10^{-2} \mu\text{m}^2/\text{h}$. Thus, the diffusion coefficient of B is larger by an order of magnitude. With these coefficients, As diffuses about 2.5 μm ,
25 whereas B diffuses about 7.5 μm .

As a result, as shown in FIG. 4, through the annealing mentioned above, B diffusing from a left-hand

side and B diffusing from a right-hand side are mixed together at a central portion of the n⁻-type epitaxial Si layer 2 having a mesa structure, which is interposed between trenches 3, and thus a rectangular p-type pillar layer 4 is formed. At the same time, on the right and left sides of the layer, a rectangular n-type pillar layer 5 is formed in a self-alignment manner.

The measurement of the p-type pillar layer 4 taken in the lateral direction is about 10 μm , and the measurement of the n-type pillar layer 5 taken in the lateral direction in each side is about 2.5 μm . Therefore, the width of the unit cell is about 15 μm , which is about a half of that of the conventional case. In this manner, the measurements of the element can be easily reduced.

In this embodiment, the npn pillar structure is formed by diffusing B and As actively in the lateral direction, and therefore the diffusion of B in the lateral direction does not hinder the reduction of the size of the element unlike the case of the conventional super junction structure.

The semiconductor structure that is made of the n-type pillar layer 5/the p-type pillar layer 4/the n-type pillar layer 5, which line up in the lateral direction, that is, the new withstand voltage structure (npn pillar structure) of the present invention, serves substantially the same functions as that of the

conventional super junction structure. Therefore, the reduction of the ON resistance (1/3 or less of that of the planar type element shown in FIG. 21) and the increase in the withstand voltage can be achieved at the same time.

Further, the above-described structure can be realized merely by ion-implantation of As and B to the side surfaces of the pillar layer. Where the total amount of B in the p-type pillar layer 4 is represented by N_B , and the total amount of As in the n-type pillar layers 5 that sandwiches the p-type pillar layer 4 from both sides is represented by N_{AS} ,

a relationship : $100 \times |N_B - N_{AS}| / N_B \leq 5$ can be satisfied.

The control of the amount of the impurity at a high accuracy can be achieved by merely ion implantation of As and B into the side walls of each trench. Thus, the dispersion in the impurity concentrations in the p-type pillar layer 4 and n-type pillar layers 5 can be sufficiently inhibited. Consequently, the increase in the dispersion in element characteristics can be suppressed.

In the figure, the pn junction surface between the n-type pillar layer 5 and the p-type pillar layer 4 is illustrated to be vertical to the surface of the n^+ -type Si substrate 1. However, in practice, since each trench 3 is formed by the RIE process, the pn

junction surface is displayed from the vertical position by a portion corresponding to the inclination of the side wall of the trench 3. That is, the pn junction surface between the n-type pillar layer 5 and the p-type pillar layer 4 is approximately vertical to the surface of the substrate 1.

Next, as shown in FIG. 5, an insulating film 6 is formed on the entire surface such that the film is embedded in the trenches 3. The insulating film 6 is formed by the following manner. That is, for example, an SiO_2 film is formed on the side surfaces of each trench 3 by thermal oxidation, and after that an SiO_2 film or SiN film is deposited on the entire surface by CVD (Chemical Vapor Deposition). In this manner, such a structure that the npn pillar structure is surrounded by the insulating film 6 can be formed.

Next, as shown in FIG. 6, the surface is planarized by CMP (Chemical Mechanical Polishing) and the unnecessary portions of the insulating film 6, that are outside the trenches 3 are removed, thereby carrying out separation of element (Deep Trench Isolation). It should be noted here that etching may be employed in place of CMP. As shown in FIG. 2B, when over-etching is carried out, the level of the bottom surface of the insulating film 6 will be lower than the level of the surface of the n^+ -type Si substrate 1 located underneath the npn pillar structure.

The following processing step from the above-described one is the same as that of the conventional planar type power MOSFET. Specifically, as shown in FIG. 7, the manufacturing process proceeds in the following order: the step of forming a p⁺-type base layer 7 on the surface of the p-type pillar layer 4, the step of forming a n⁺-type source diffusion layer 8 selectively on the surface of the p-type base layer 7, the step of forming a gate insulating film 9 and gate electrode 10 on the p⁺-type base layer 7 interposed between the n⁺-type source diffusion layer 8 and the n-type pillar layer 5, and the step of forming the source electrode 11 and drain electrode 12. It should be noted that FIG. 7 illustrates three unit cells.

In this figure, the interlayer insulating film that covers the gate electrode 10 and has contact holes made for the source electrode 11 and the like, is denoted by the same reference numeral, that is 9, as that for the gate insulating film.

FIG. 8 is a perspective and cross sectional view illustrating a stage where the process has reached up to the formation of the n⁺-type source diffusion layer 8. The pattern obtained by observing the npn pillar structure from above is in stripes as shown in the figure. The gate electrode 10 is, for example, a polysilicon gate, a polycide gate or a metal gate.

The power MOSFET of this embodiment can be

manufactured by adding only 5 steps to the manufacturing method for the conventional planar type power MOSFET shown in FIG. 21. The 5 steps are specifically, a step of forming a deep trench 3, a step of ion-implantation of As and B, a step of activating ion-implanted As and B by annealing, a step of forming an insulating film 6 serving as an element separation insulating film and a step of removing unnecessary portions of the insulating film 6 by CMP.

By contrast, in order to manufacture a planar type power MOSFET having a super junction structure shown in FIG. 21, it is necessary to add 5 or 6 times of an epitaxial growth step, 10 or 12 times of a mask formation step and 10 or 12 times of an ion implantation step to the manufacturing process for the conventional planar power MOSFET shown in FIG. 21.

That is, according to this embodiment, a planar type power MOSFET having substantially the same structure as that of the device shown in FIG. 22 can be manufactured in far less processing steps than that of the conventional case.

The improvement technique and termination structure of the DT MOS according to this embodiment will now be described. First, the technique of uniformizing the ion implantation amount will now be described.

FIG. 9A is a plan view illustrating the planar

pattern of an outermost cell corner portion (a corner portion of an element region including a plurality of DTMOSSs) in the case where the planar pattern of the npn pillar structure formed by the rotation ion implantation method is in stripes. Further, FIG. 9B is a cross sectional view taken along arrows A - A' shown in FIG. 9A, and FIG. 9C is a plan view taken along arrows B - B' shown in FIG. 9A.

From FIGS. 9A to 9C, it can be seen that the width t_1 of the n-type pillar layer 5 in the corner portion of the npn structure in stripes is larger than the width t_2 of the longitudinal straight portion of the npn pillar structure in stripes.

The difference between the widths t_1 and t_2 indicates that there is a difference between the total amount of the impurity ion-implanted to the corner portion and that of the impurity ion-implanted to the longitudinal straight portion. The difference in the total amount of the impurity causes a decrease in the reverse directional withstand voltage between the source and drain.

The above-described drawback can be solved by the followings. That is, as shown in FIGS. 10A to 10C, the npn pillar structure of the outermost cell corner portion and the corner portion of the planar pattern of the insulating film 6 that is in contact with the pillar structure is rounded in shape, so as to make

t1 = t2.

In this manner, the imbalance in terms of the total amount of impurity can be redressed, thereby making it possible to assure a stable drain-source reverse directional withstand voltage. The shape of the npn pillar structure is determined by the shape of the trench 3, and therefore in order to round the shape of the corner portion, it suffices only if the shape of the trench 3 is changed.

In this embodiment, the corner portion is rounded to have a semicircular shape; however it is alternatively possible that it is modified into a polygonal shape. That is, as long as the corner portion is modified into a shape in which there is no 90-degree edge, the imbalance in the total amount of impurity can be remedied. Therefore, the decrease in the drain-source reverse directional withstand voltage can be suppressed.

FIG. 11 shows a typical example of the gate wiring structure for gate electrodes of a plurality of DTMOSSs formed in package. In this figure, reference numeral 13 denotes a MOSFET cell portion consisting of a plurality of DTMOSSs (an element region including a plurality of DTMOSSs), numeral 14 denotes a gate wiring (the first gate wiring) of the outer region of the chip (peripheral portion of the element region including a plurality of DTMOSS) and numeral 15 denotes

a gate pad.

In the case of the gate wiring structure having the above-described configuration, the charge/uncharge of the gate electrode in ON/OFF switching operations is delayed at the central portion (chip central portion) of the MOSFET cell portion 13. Such delay hinders the increase in speed of the switching operation.

The drawback described above can be solved in the following manner. That is, as shown in FIG. 12, it suffices if a gate wiring (second gate wiring) 16 that extends from the gate wiring 14 to the central portion of the MOSFET cell portion 13 is added. With this arrangement, the gate resistance can be reduced, and the delay at the central portion of the MOSFET cell 13 (the central portion of the chip) can be redressed, thereby making it possible to easily increase the speed of the switching operation.

Further, the gate wiring 16 can be formed by the same step as that of the gate wiring 14, and therefore no additional step is necessary. Therefore, when the gate wiring structure shown in FIG. 12 is employed, the advantage that the DTMOS can be manufactured at a low cost can be assured as it is so with the conventional case.

FIG. 13 shows an underlying structure of the gate wiring structure. FIG. 14 is a cross sectional view taken along arrows A-A' in FIG. 13, and FIG. 15 is a

cross sectional view taken along arrows B-B' in
FIG. 13. The element region underneath the gate wiring
16 (gate wiring region) and the element region in which
a plurality of DTMOSSs that carry out MOSFET operations
5 (MOSFET region) are physically separated from each
other by the insulating film 6. In the gate wiring
region, the npn pillar structure is formed in a similar
manner to that of the MOSFET region.

The p⁺-type base layer 7 of the MOSFET region and
10 the p⁺-type base layer 7 of the gate wiring region are
electrically connected to each other via the source
electrode 11. However, the n⁺-type source diffusion
layer 8 is not formed in the p⁺-type base layer 7 of
the gate wiring region, and therefore the MOSFET
15 operation does not occur in the gate wiring region.

FIG. 26 shows the termination structure of the
DTMOS of the present invention. The termination
structure can be formed at the same time when the DTMOS
is formed. More specifically, it can be formed in the
20 following manner. In the step of making the trench 3
illustrated in FIG. 2, a trench having a width of 10
to 30 μm is formed in the termination region of the
n⁻-type epitaxial Si layer 2 at the same time. In the
step of forming the insulating film 6 illustrated in
25 FIG. 5, the trench made in the termination region is
filled with the insulating film 6 at the same time. In
the CMP step illustrated in FIG. 6, the surface of the

termination region is planarized, and the unnecessary portion of the insulating film 6 on the trench of the termination region is removed.

5 In the case of 600V class, the required length of the termination structure shown in FIG. 24 is about 200 to 600 μm , whereas the required length of the termination structure of the present invention is small as about 100 to 20 μm , which is about 1/4 of the former case. This is because, conventionally, the
10 electrical field is relaxed with use of the n-type epitaxial Si layer 89, whereas in this embodiment, the electrical field is relaxed by the insulating film 6 formed in the termination region.

As described above, according to this embodiment,
15 there will be no substantial wasteful portion of the termination region, thereby increasing the yield of chips produced from a Si wafer. Consequently, the production cost can be reduced.

FIG. 25 illustrates another termination structure
20 of the present invention.

On an outer side (the termination region side) of an insulating film 6' that separates the DT MOS located on the outermost section of the FET operation region and the termination region from each other, n-type
25 pillar layers 5 and a p-type pillar layer 4 which are similar to those of the FET operation region are inevitably formed. The insulating film 6' is formed in

the step as that of the insulating film 6.

Here, it should be noted that on the surface of the n-type pillar layer 5 (substrate surface), the same potential as the drain potential on the rear surface of the substrate appears when applying a drain-source reverse directional voltage. Therefore, the source electrode 11 is located on the interlayer insulating film 9 which can withstand the applied voltage. The source electrode 11 is formed to be in contact with the source diffusion layer 8 of each of the DTMOSSs of the FET operation region.

Further, in order to obtain a drain-source reverse directional withstand voltage of, for example, 600V, a distance D1 between the end portion on the termination region side of the source electrode 11 and the end portion on the terminal region side of the n-type pillar layer 5, which has a high potential, (that is, the boundary between the p-type pillar layer 4 and the n-type pillar layer 5) is set to 10 μm . The reason for setting the distance D1 to 10 μm is that it has been found that a necessary withstand voltage can be obtained with a condition of $D1 \geq 2 \mu\text{m}$ or more, as indicated in FIG. 26.

With the above-described structure, the electrical field applied to the end of the source electrode 11 can be sufficiently relaxed, and therefore a stable drain-source reverse directional withstand voltage can be

secured. It should be noted here that the distance D1 is at least 10 μm ; however it is preferable that the distance D1 should not be excessively long in consideration of the reduction in size. More specifically, it is, preferably, 15 μm or less.

Then, the gate wiring structure, which will now be described, is formed on the termination region. The gate wiring structure consists of the gate electrode 10 and the gate wiring 14 (the gate wiring 16 described before as a preferable example), and the distance D2 between the gate electrode 10 and the gate wiring 14 is set to about 5 μm .

By employing the above-described gate wiring structure, it suffices if the measure Lend of the termination region is set about 155 μm in order to assure, for example, 600V of a drain-source reverse directional withstand voltage. This value is only about 1/4 of the measurement of the termination region of the conventional planar type insulated gate field effect transistor. In other words, the measure Lend of the termination region can be remarkably reduced by providing a simple gate wiring structure in the termination region.

The above-described technical features for improving the DTMOS (more specifically, the technique for rendering the implantation amount uniform and delay inhibiting technique) and the termination structure can

be combined appropriately. Further, they can be applied as well in a similar manner to the second to fourth embodiments that will now be described.

(Second embodiment)

5 FIG. 17 is a perspective and cross sectional view illustrating a power MOSFET according to the second embodiment of the present invention. It should be noted that the parts of this embodiment that correspond to those shown in FIGS. 1 to 16 will be designated by
10 the same reference numerals, and the detailed descriptions therefor will not be repeated. (This is also the case for the embodiments from the third one on.)

 The point of this embodiment that is different
15 from that of the first embodiment is that the pattern of the npn pillar structure taken from above (that is, a planar pattern) is made into a so-called offset mesh-like pattern. With this structure, the channel density can be increased in some cases depending on
20 the measurements of the element. It is alternatively possible to make the pattern of the npn pillar structure taken from above (that is, a planar pattern) into a so-called mesh-like pattern (, which is a pattern in which two npn pillar structure arranged in
25 up and down direction are not displaced with respect to each other in a lateral direction).

(Third embodiment)

FIG. 18 is a cross sectional view illustrating a power MOSFET according to the third embodiment of the present invention.

5 The point of this embodiment that is different from the first embodiment is that an n^+ -type diffusion layer 17 that has a high impurity concentration is formed on the surface of the n -type pillar layer 5.

10 In the case where there is no n^+ -type diffusion layer 17, a depletion layer is expanded on the surface of the n -type pillar layer 5 when a voltage is applied between the source and drain. Therefore, if a charge of Na ion or the like is attached to the surface of the n -type pillar layer 5, the depletion is partially
15 inhibited. Then, the electrical field is concentrated to the portion where the depletion is inhibited, thereby possibly causing a breakdown.

20 By contrast, in this embodiment, the n^+ -type diffusion layer 17 is formed on the surface of the n -type pillar layer 5. With this structure, the expansion of the depletion layer on the surface of the n -type pillar layer 5 can be prevented, thereby making it possible to avoid the above-described drawback. Further, the n^+ -type diffusion layer 17 can be formed
25 at the same time as that of the n^+ -type source diffusion layer 8, which is formed by ion implantation and annealing, and therefore the number of steps is not

increased. As described above, the n⁺-type diffusion layer 17 and the n⁺-type source diffusion layer 8 are formed by the same ion implantation and annealing, and therefore the their impurity concentrations are substantially the same.

(Fourth embodiment)

FIG. 19 is a cross sectional view illustrating a power MOSFET according to the fourth embodiment of the present invention.

The point of this embodiment that is different from the first embodiment is that the deep trench 3 is filled with not only the insulating film 6, but also with the polysilicon layer 18 together with it.

In more detail, the insulating film 6 (the first insulating film) made of, for example, an SiO₂ film having a thickness of about 1 to 2 μ m is formed by a deposition or thermal oxidation method on the bottom surface and side surfaces of the trench 3 having a width of about 8 μ m. Then, the polysilicon layer 18 is deposited on the entire surface. After that, the unnecessary portion of the polysilicon layer 18, which is located outside the trench 3, is removed by CMP or etching. At the same time, the portion of the polysilicon layer 18, which is located underneath the opening surface of the trench 3, is removed. Next, the not-yet filled portion underneath the opening surface of the trench 3 is filled with an insulating film (cap

insulating film) 6c (the third insulating film), and the upper surface of the polysilicon layer 18 is thus capped. The insulating films 6 and 6c serve to cover the bottom surface, side surfaces and the upper surface of the polysilicon layer 18 formed on the n⁺-type Si substrate 1.

In order to form the polysilicon layer 18 in the trench 3 with priority, a silicon oxide film (the second insulating film), which is not shown in the figure, may be formed on the surface of the n⁺-type epitaxial Si layer 2. Then, the trench 3 may be opened up, and the bottom surface and side surfaces of the trench 3 should be covered with a silicon nitride film (the first insulating film). After that, the polysilicon layer 18 may be grown by the CVD method.

Since the polysilicon layer 18 is not a current path, it need not be completely embedded. For this reason, the polysilicon layer 18 can be formed more quickly than the insulating film 6. It can be formed at a film forming speed of, for example, about 1 $\mu\text{m}/\text{min}$.

Since Si is grown from both sides of the trench 3, the film forming speed the trench 3 having a width of 5 μm can be filled in 2.5 minutes in the case of the above-mentioned film forming speed. Thus, according to this embodiment, the deep trench 3 can be filled in a short period of time, and therefore the processing

time can be shortened.

Further, the polysilicon layer 18 has a thermal expansion coefficient equal to that of the n-type pillar layer 5 and the p-type pillar layer 4.

5 Therefore, as compared to the case where the entire trench 3 is filled only with the insulating film, a large thermal stress is not applied to the Si portion located underneath the trench 3 if it undergoes a heat process after separation of elements. In this manner,
10 it is possible to prevent a crystal defect from occurring in the Si portion, which causes such a drawback as increasing the leak current.

Furthermore, according to this embodiment, a voltage can be shared by the insulating film 6c on
15 the upper surface of the polysilicon layer 18 and the insulating film 6 on the lower surface of the polysilicon layer 18. Therefore, the withstand voltage can be raised as compared to the case where the trench 3 is filled with the insulating layer 6 and the
20 polysilicon layer 18.

It should be noted here that the insulating film 6c is not essential to this embodiment. FIG. 20 shows an element structure that does not include the insulating film 6c. In this case, it is not necessary
25 to remove the polysilicon layer 18 located underneath the opening surface of the trench 3.

When the concentration of the n-type impurity in

the n-type pillar layer 5 is set to 12×10^{15} (atoms/cm³) at peak and the concentration of the p-type impurity in the p-type pillar layer 4 is set to 4×10^{15} (atoms/cm³) at peak, this element structure was compared with the conventional planar type shown in FIG. 21 for the same withstand voltage ($V_{dss} = 720$ (V)) in terms of ON resistance. With the result, it was confirmed that the ON resistance could be reduced to about 24% ($R_{on} = 0.36$ (Ω)) of that of the conventional type.

The concentrations of these impurities are not limited to these values provided above, but it has been confirmed that, for example, the concentration of the n-type impurity in the n-type pillar layer 5 may be about 3 to 18×10^{15} (atoms/cm³) and the concentration of the p-type impurity in the p-type pillar layer 4 may be about 0.2 to 8×10^{15} (atoms/cm³) to obtain a similar effect to the above. Further, it suffices if the concentration of the n-type impurity in the n-type epitaxial Si layer 2 is about 5×10^{13} to 3×10^{14} (atoms/cm³).

It should be noted that the present invention is not limited to those of the embodiments described above, but it is alternatively possible that, for example, the channel is of the p-type in place of the n-type. Further, it is possible that the power MOS transistor and some other circuits including the

control circuit and protection circuit are formed within the same chip.

In addition, the above-described embodiments include various stages of inventions, and structural elements disclosed in these embodiments can be combined
5 appropriately to extract various versions of the present invention. For example, if some of the structural elements presented in an embodiment are deleted from the entire structure, the version of the
10 invention that can be obtained from such a structure from which some of the elements have been deleted can be extracted as an invention as long as the object of the invention can be achieved with that structure. Apart from the above, the present invention can be
15 modified into various versions as long as the essence of the invention remains within the scope thereof.

Industrial Applicability

According to the present invention, there is provided a semiconductor device equipped with a power
20 MOSFET, which can achieve both of a decrease in ON resistance and an increase in withstand voltage, and can be manufactured without having to significantly increase the number of processing steps, as well as its manufacturing method.